CMS-Wave Model: Part 3. Grid Nesting and Application Example for Rhode Island South Shore Regional Sediment Management Study

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PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the grid nesting capability of the Coastal Modeling System (CMS) wave model CMS-Wave available in the U.S. Army Corps of Engineers (USACE) Surface-water Modeling System (SMS). The grid nesting for wave transformation is useful in applications where a smaller computational domain resides fully or partially inside a larger grid domain. The theoretical background and user's manual for CMS-Wave are provided by Lin et al. (2008). CMS-Wave is part of the CMS developed under the Coastal Inlets Research Program (CIRP) for simulating combined waves, currents, sediment transport and morphology change at coastal inlets, estuaries and river mouths (Lin et al. 2006; Demirbilek et al. 2007).

BACKGROUND: CMS-Wave is a two-dimensional (2-D) spectral wave transformation model that employs a forward-marching, finite-difference method to solve the wave action conservation equation (Mase et al. 2001). Capabilities of CMS-Wave include wave shoaling, refraction, diffraction, reflection, transmission over structures, depth-limited breaking, dissipation, wave-wave interaction, wave-current interaction, and wave-structure interactions. Wave diffraction is implemented by adding a diffraction term derived from the parabolic wave equation to the energy-balance equation (Mase et al. 2005). CMS-Wave operates on a coastal half-plane so primary waves can propagate only from the seaward boundary toward shore. Shoreward and seaward reflection are treated using the mirror reflection principle. CMS-Wave is coupled to CMS-Flow (Buttolph et al. 2006), a hydrodynamic and sediment transport model, to calculate the morphology change forced by tides, currents and waves. Readers are referred to the CMS-Wave technical report by Lin et al. (2008) for additional information about the model.

Multiple grid nesting can consist of several large and small grids. The simplest and most commonly applied grid nesting involves two model grids: a large grid (parent grid) and a small grid (child grid). The application of grid nesting can substantially reduce the computational time of large grids that employ a number of sub-grids with finer resolution. A parent grid with coarser resolution may be used to simulate the regional processes such as wave generation and propagation in a large domain. A child grid with finer resolution can resolve more complex bathymetry and shoreline geometry in a smaller area. Wave spectra calculated from a large domain coarser grid are saved at selected locations along the offshore boundary of a smaller fine resolution grid. Traditionally, a single-location spectrum is saved from the parent grid for wave input applied to the entire sea boundary of the child grid. Multiple-locations wave spectra may be saved from the parent grid and interpolated for more realistic wave forcing along the seaward boundary of the child grid. The two main goals of grid nesting are to minimize the computational time and maximize wave modeling accuracy (Smith and Smith, 2002).

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NESTING METHOD: In a nested grid approach, wave spectra calculated from a large-domain coarser resolution grid (called parent grid) are saved at selected points along the offshore boundary of a small domain finer resolution grid (called child grid). The wave spectra are saved from the parent grid for input to the child grid. The saved information also includes the parent grid orientation, coordinates of save locations where directional spectra are saved, significant wave height, and associated wind speed and direction. For the child grid, CMS-Wave reads and interpolates the saved spectra as input for wave transformation over the small domain. The parent and child grids may have different orientations, but both grids must be in the same horizontal coordinate system. Because CMS-Wave is a half-plane model, the difference between grid orientations of parent and child grids should be small (less than 45 deg). This is necessary for passing a comparable amount of wave energy from the parent to the child grid.

There are two options available CMS-Wave for projecting (or mapping) the parent grid output spectra to the child grid incident wave input. These are the average and morphic methods. In the average method, the saved wave spectra from the parent grid at selected points along the offshore boundary of the child grid are averaged and projected to the child grid half-plane to provide a single incident wave spectrum as input to the child grid. In the morphic method, the energy density for each wave spectrum frequency-direction bin along the child grid offshore boundary is interpolated among all bins of the saved spectra from the parent grid. The weighting factors of interpolated directional spectra are based on the relative spatial distances between save locations and individual direction bins along the offshore boundary of the child grid.

CMS-Wave grid nesting for parent and child grids can be set up in SMS version 10.1 and higher. After generating the parent and child grids, the user first needs to specify the save locations in the parent grid along the offshore boundary of the child grid. In the SMS, the CMS-Wave model is controlled through the 2-D Cartesian grid module. The user can select the *Switch Current Model* command in the *Data* menu and choose CMS-Wave to activate the model interface if it is not presently the default (active) model. Using the *Select Grid Cell* in the tool box, the user can select a set of save cells in the parent grid along the offshore boundary of the child grid by clicking the selected cells while holding the *Shift* key. In the *CMS-Wave* menu, the user can choose *Nesting Output* under the *Select Cell Attributes* command to complete the parent grid setting. For the child grid, the user only need select the *Nest Grid* in the *CMS-Wave* menu and provide the input incident spectrum file from the parent grid and interpolation option under the *Child Grid* option.

Figure 1 shows an example of one parent and one child grid with eight save cell locations (black squares) in the parent grid along the offshore (east) boundary of the child grid. In this example, the child grid is nested in the middle of parent grid. The parent grid domain is 17 km x 10 km with a constant cell size of 100 m by 100 m. The child grid dimension is 4.3 km x 3.7 km with a constant cell size of 50 m x 50 m. The grid origins, corresponding to the local grid x- and y-axis triads in Figure 1, of the parent and child grids are located at the upper right corner of their respective domains. These grid orientations are referenced to the SMS Cartesian coordinate system with the global x-axis pointing to East. Grid orientations for the parent and child grids in Figure 1 are 165 and 190 deg, respectively. The incident wave forcing is applied along the offshore (east) boundaries of both parent and child grids. Figure 2 shows the calculated wave field in the parent grid with an incident unidirectional wave spectrum of 3-m wave height and 10-sec peak period, from ESE. Figure 3 shows the calculated wave field for the child grid over the

parent grid, with a small island included in the middle of the child grid. Wave diffraction and convergence around the small island cause wave heights to increase locally in parts of the finer grid resolution in the child grid. The user can select the *Assign Cell Attributes* under the *CMS-Wave* menu to add an artificial island such as in Figure 3 child grid, or others types of structures such as submerged reefs, breakwaters, seawalls, jetties, etc. without modifying the original bathymetry. Refer to Lin et al. (2008) for available structure cell attributes of CMS-Wave.

CMS-Wave can be run as a stand-alone model or in coupled mode with CMS-Flow. The coupled flow-wave mode is handled in the SMS *Steering Module* under the *Data* menu to calculate the interactions of tides, currents and waves. In the Steering mode, CMS-Flow provides the water level and flow field input data to CMS-Wave. Wave height, period, direction, and radiation stress components calculated by CMS-Wave are input to CMS-Flow. The user can choose to run either the parent or child grid or both grids in the Steering mode. If the parent grid is run in the Steering mode, an "nst.dat" file will be automatically generated from the run that saves the calculated spectra at output cell locations along the offshore boundary of the child grid. The spectra file (nst.dat) saved from the parent grid along the offshore boundary of the child grid should be renamed to "nest.dat" which should be used as the incident wave input for the child grid Steering run. It is noted that this "nest.dat" is only required for the child grid steering run. The parent grid run must be conducted and completed first to start child grid runs irrespective of whether CMS-Wave is or is not coupled with CMS-Flow.

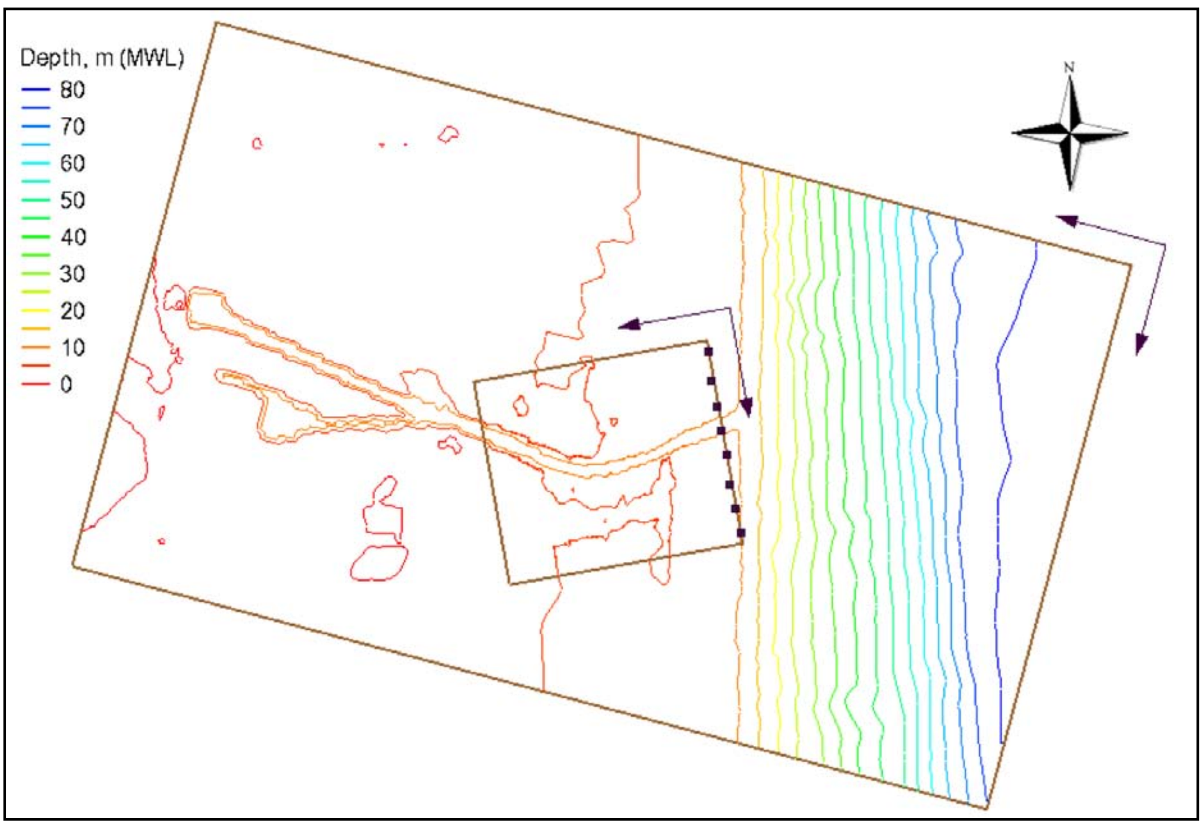

Figure 1. A large parent grid (17 km x 10 km) and a small child grid (4.3 km x 3.7 km) with save cell locations (black squares) in the parent grid along the offshore boundary of the child grid.

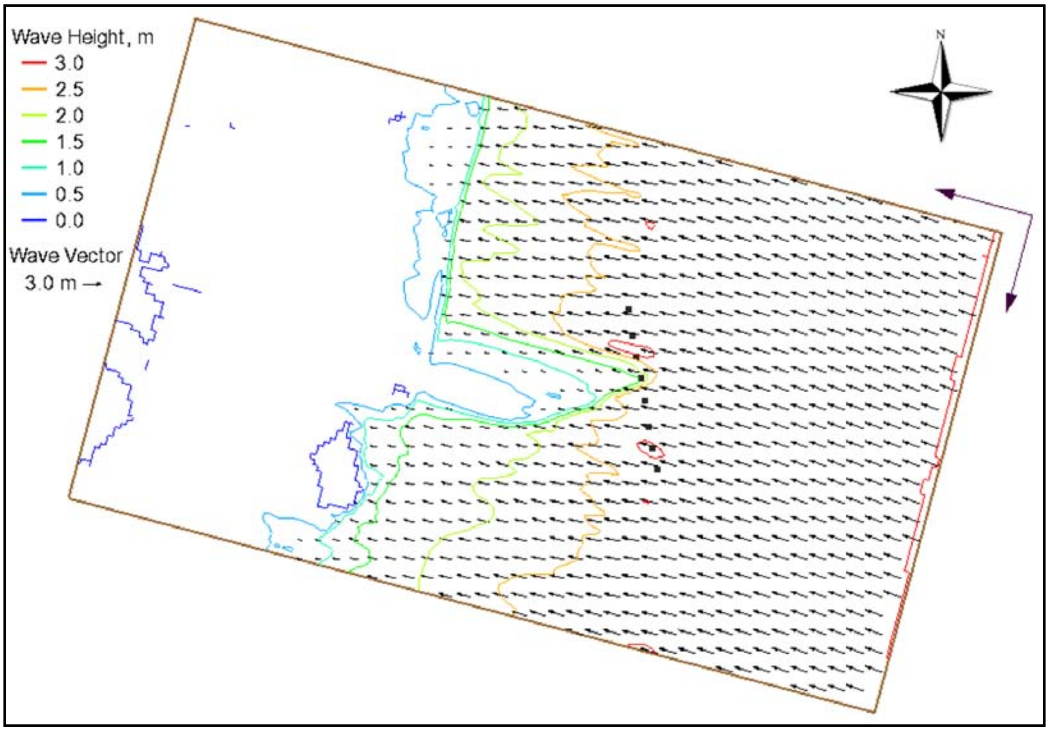

Figure 2. Calculated wave field in the parent grid with the save cell locations (black squares) from an incident unidirectional wave of 3m and 10sec from ESE.

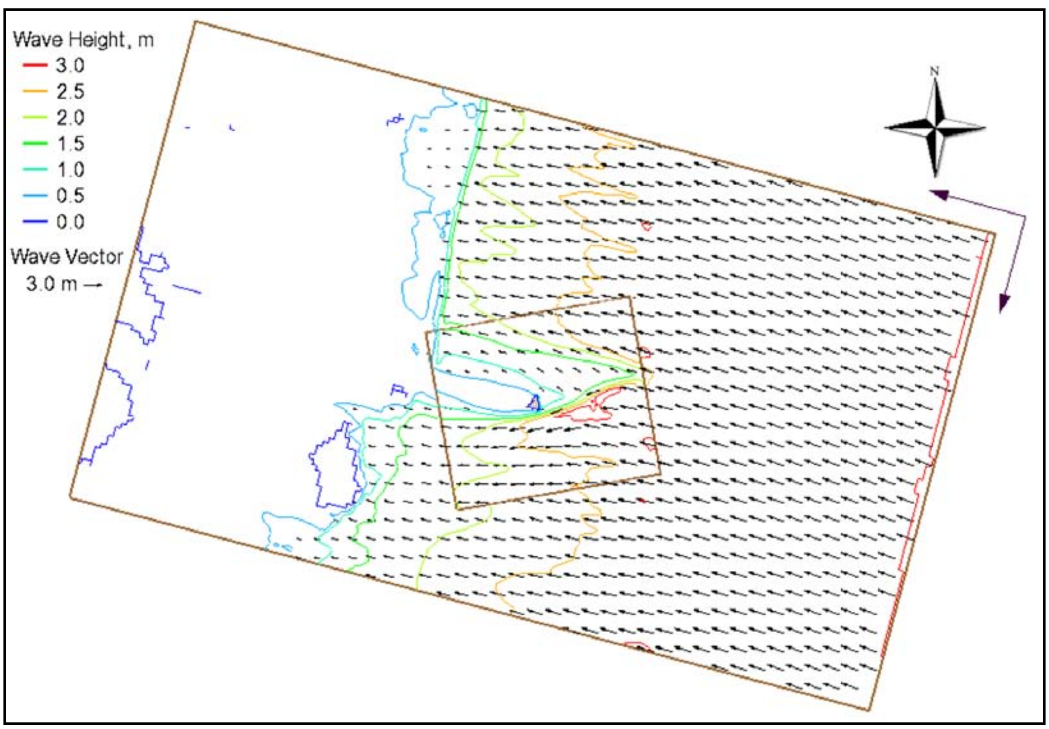

Figure 3. Calculated wave fields in the child and parent grids with a small artificial island added in the middle of the child grid.

EXAMPLE APPLICATION -- Nested Grids for Rhode Island South Shore: The grid nesting capability of CMS-Wave coupled with CMS-Flow is illustrated in this section for the Rhode Island South Shore Regional Sediment Management (RISRSM) study.

Background: Regional Sediment Management (RSM) is the effective utilization of littoral, estuarine, and riverine sediment resources in an environmentally effective and economic manner (Martin, 2004). The motivation behind RISRSM is to identify the sediment pathways in a system at a regional scale for management of sediment based on a system approach. The RISRSM is developing a management plan for sediments along the project study area that consists of a 38 km stretch of shoreline of the south shore of Rhode Island, stretching from Point Judith at the eastern extent to Little Narragansett Bay at the western extent. Figure 4 details the geological boundaries and the salt pond configurations.

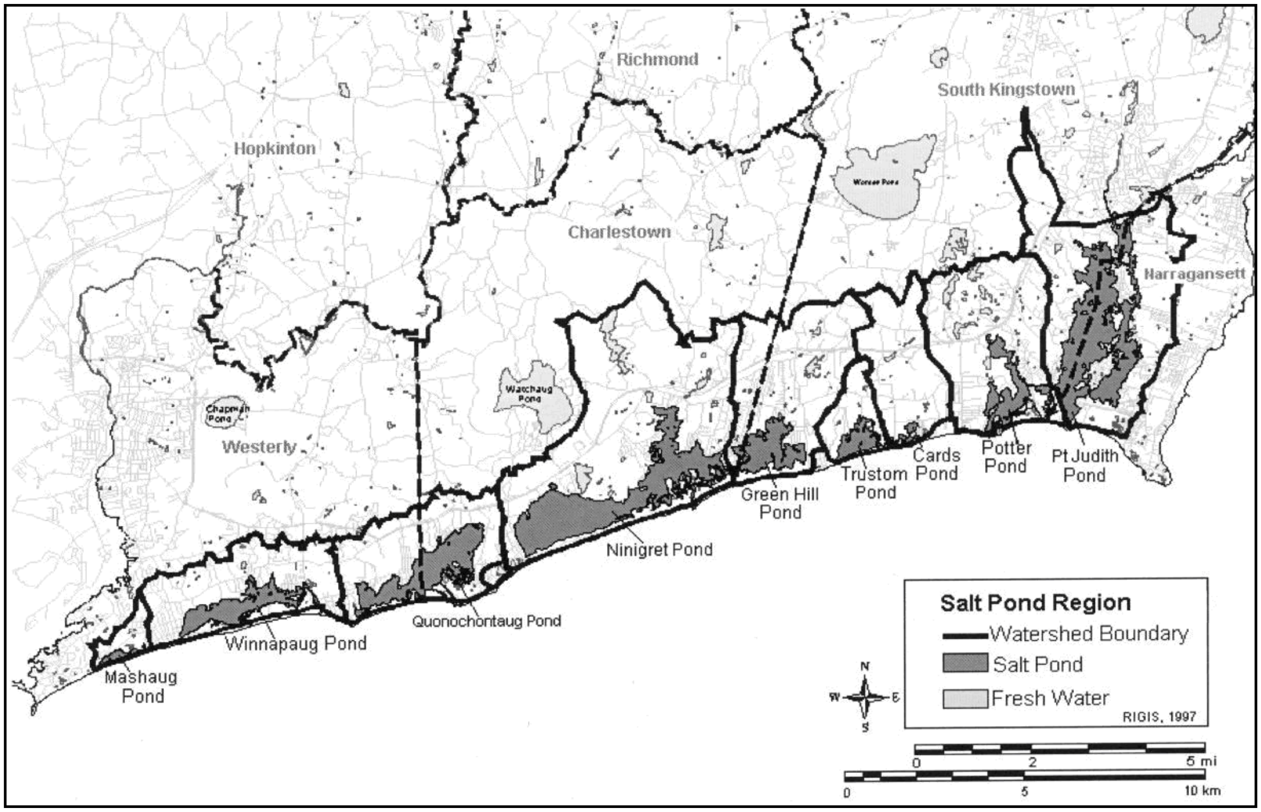

Figure 4. Rhode Island Regional Sediment Management project area (Ernst et al., 1999).

The key features of this area include a series of glacial outwash headlands, barrier islands, and salt ponds. The salt ponds represent both critical wetlands habitat and also provide protection to the infrastructure built behind the ponds. These are shallow ponds, with an average depth of 1 to 2 m, and range in size from 16 to 688 ha (40 to 1,700 acres). The salinities of the ponds depend on the amount of fresh water entering the ponds. The salt pond watershed covers 83 square km. The shallow salt ponds are prone to wetting and drying. Bathymetry of the ponds has been generated via Light Detection and Ranging (LIDAR) flights performed in 1999. The deepest pond depths occurred in Quonochontaug pond which had a range of 1.4 m to 3.8 m NAVD88. Winnapaug follows with a range of 0.8 m to 1.7 m NAVD88. Finally, Ninigret and Green Hill Ponds

are the shallowest of the ponds with a range of 0.3 m to 0.8 m NAVD88. The remaining pond depths are not available from this dataset. These depths should be used with caution due to turbidity concerns and algal blooms occurring during this Lidar flight. It is estimated from field verification that water depths reported from the 1999 Lidar flight are approximately 0.5 m shallow. Lidar flight over the ponds is to be repeated during the data collection phase of the study which will further aid model development. The sizes of each of the salt ponds are: Ninigret Pond (1711 acres), Green Hill Pond (431), Winnapaug Pond (446) and Quonochontaug Pond (732) (NAE, 2002). Inlet widths of the salt ponds range from approximately 27 to 89 m, and each pond may behave differently in hydrodynamics and sedimentation properties. The ponds are isolated and are independent of other neighboring ponds.

The study area includes two Federal navigation channels (Little Narragansett Bay and Point Judith Harbor, a Federal Harbor of Refuge (Point Judith), one newly completed Section 206 (Aquatic Ecosystem Restoration and Protection of the Water Resources Development Act of 1996) habitat restoration project (Ninigret Pond) and two proposed Section 206 projects (Quonochontaug and Winnapaug Ponds) for removing portions of flood shoal deltas for habitat restoration. The RSM plan includes three Federal navigation projects and six existing or proposed Federal projects, all of which involve movement/placement of sediments within 38.6 km of shoreline. There are four jettied inlets within the study area at Winnapaug, Quonochontaug, Ninigret, and Point Judith.

The features of the study area pose a unique challenge for numerical modeling because it is necessary to evaluate a number of processes over the entire area at the highest resolution possible. These processes include but are not limited to wetting and drying, ebb and flood shoal formation, erosion and accretion at each pond, determination of velocities through inlets and effects of inlet structures on adjacent beaches. To efficiently quantify these processes at a regional scale without sacrificing grid resolution, the nested wave grids become necessary. By employing nested grids to study sediment transport, one can expedite computations by invoking finer grid resolution only over those smaller child grids covering the individual ponds and thereby using a coarser grid for the regional scale. The following describes the model set up for two ponds plus the regional grid.

Grid generation: A large regional-scale CMS-Wave grid was first developed using available LIDAR data (2007) and Geophysical Data System (GEODAS) data (*http://www.ngdc.noaa.gov/mgg/geodas/geodas.html*). The LIDAR data is to be updated with the spring flight data in 2010. The large grid contains a total of 375,000 square cells, each of 200 m x 200 m. The incident wave data as input to this regional grid is from an offshore buoy CDIP 154 (NDBC 44097) in 48-m water depth. Figure 5 shows the extent of the regional bathymetry grid and five nested child grids covering the coastal salt ponds. Each child grid is generated with variable rectangular cells ranging from larger cells of 50 m x 50 m in the offshore to small cells of 4 m x 4 m in the pond inlet area. Figure 6 shows the child grid for Ninigret Pond. At least 5 water cells are required across the inlets for sufficient flow exchange between the ponds and ocean, expected to be calculated as part of the RISRSM.

Application of Grid Nesting: The regional and pond grids are nested together as a seamless system to run CMS-Wave and CMS-Flow in the Steering mode in the SMS interface. The forcing in the regional grid includes the incident waves and water level input along the ocean

boundaries. The incident waves are the directional spectra from the nearest offshore buoy (CDIP 154). The water level along the ocean boundary is from the Le Provost database. In the Steering mode, the water level and flow field input data for CMS-Wave are provided by CMS-Flow. The CMS-Wave results including wave height, period, direction, and radiation stress components are input to CMS-Flow. In the child grids simulations, the input water level, flow and incident wave conditions are provided by the parent (regional) grid. The sediment transport calculated by CMS-Flow and wave run-up and overtopping calculated by CMS-Wave are activated only in the child grid.

The RSM Rhode Island study is a 5-year project started in October 2009. The field data collection includes tide data inside the ponds and ADCP current data in the inlets. Tide data and current data will be collected outside the ponds on the open coast by ADCP gauges for wave measurements. The validation of CMS grid nesting at this site will be conducted when the field data become available, and results will be reported in a technical report later in 2010.

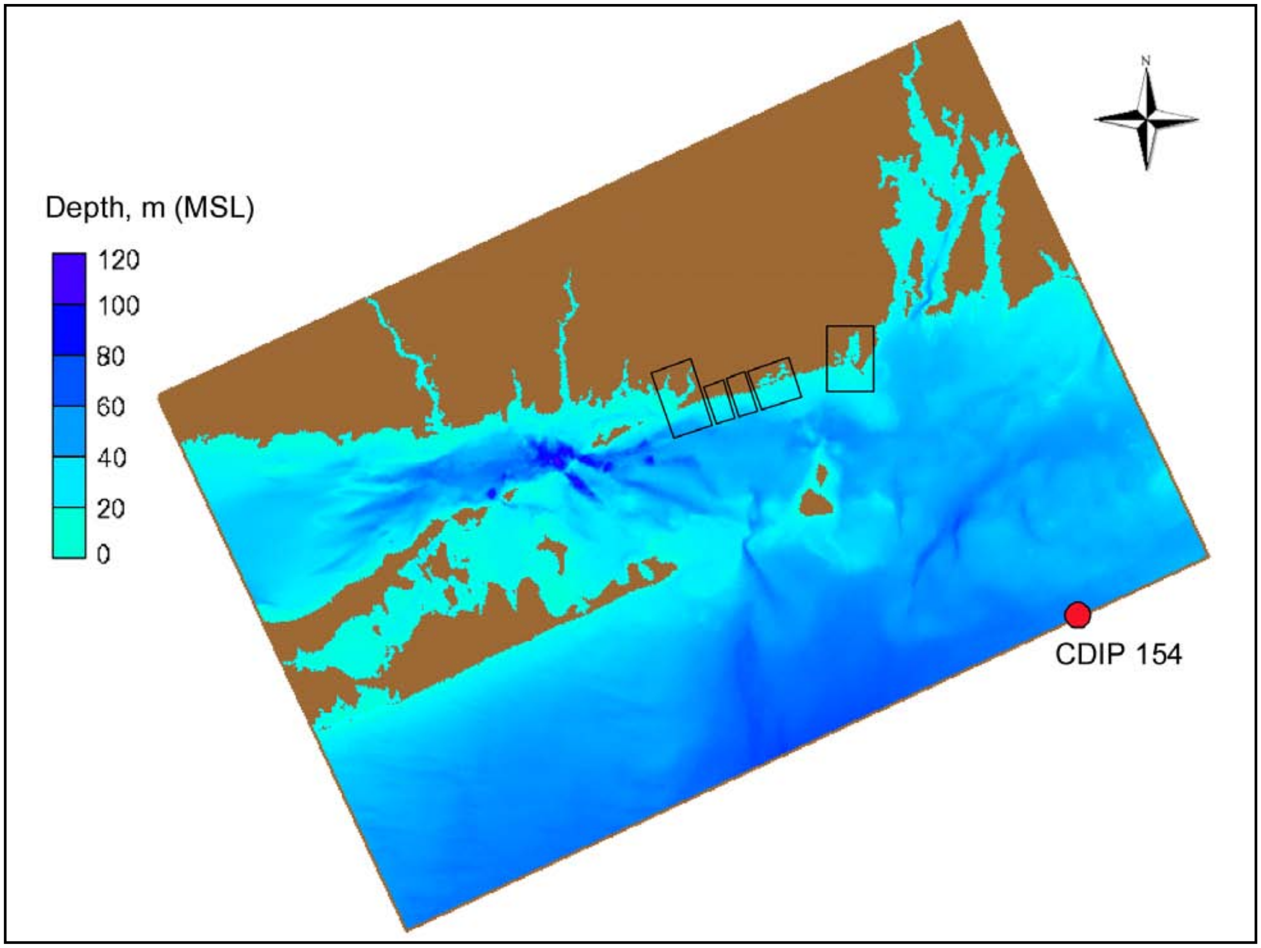

Figure 5. Regional grid configuration.

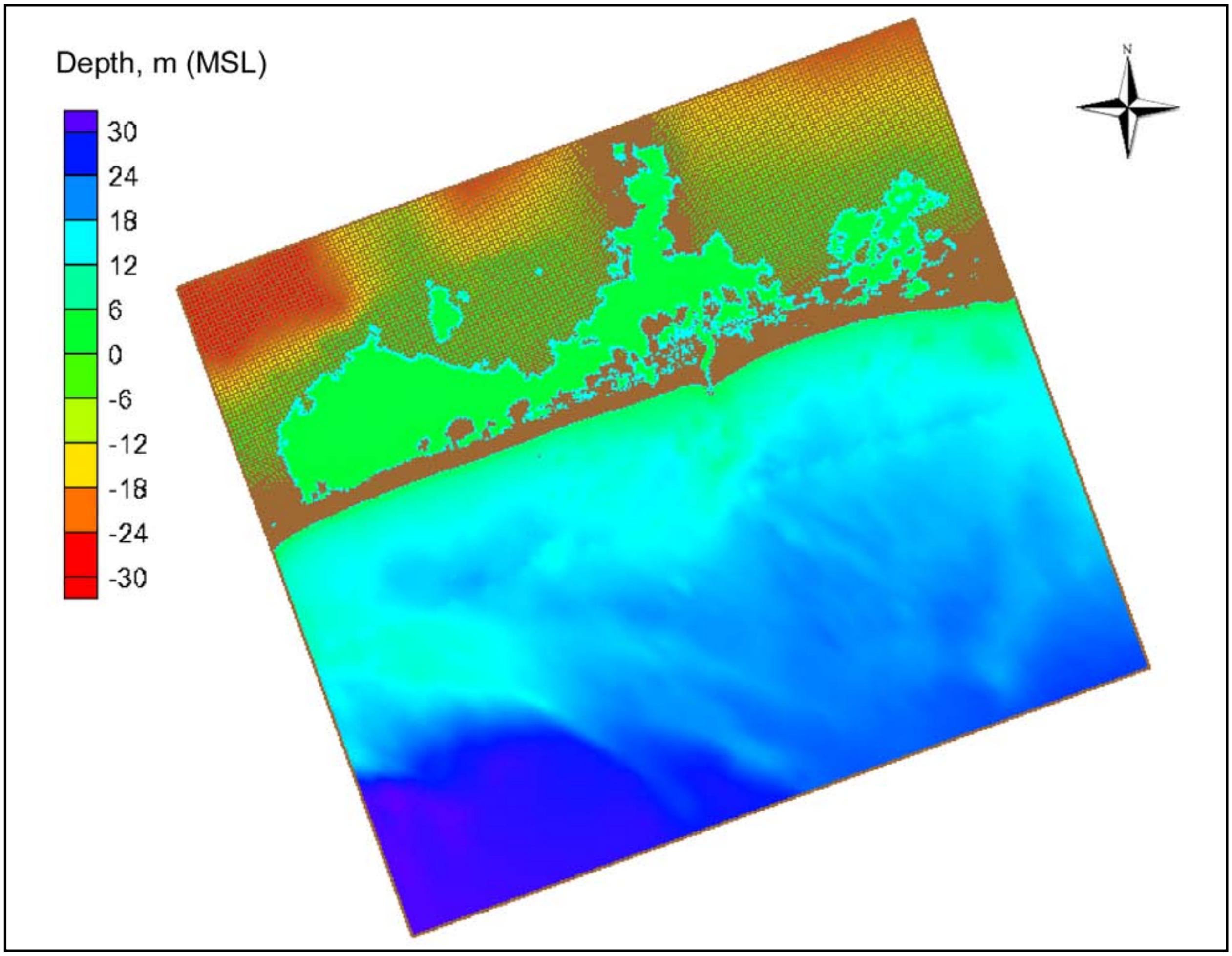

Figure 6. Ninigret Pond grid configuration.

CONCLUSION: This CHETN describes the grid nesting capability of the CMS-Wave model for coastal and nearshore wave transformation applications that recently became available within the SMS version 10.1 and higher. Grid nesting is not necessary, but is useful in applications with large grids to efficiently model regional processes and with small grids to resolve details of complex bathymetry and shoreline geometry near the coast. An alternative would be to run one large domain with a finer grid resolution, which would require considerably longer computational times. The advantages of grid nesting include a reduction in computational time and improved accuracy of wave and flow modeling predictions. These advantages are achieved by running a large domain grid with a coarser resolution and several small domain grids with a finer resolution. Another advantage of the grid nesting is that it allows the user to incorporate structures in the small domains without rerunning the large domain regional grid. The usefulness of grid nesting is demonstrated in this CHETN for the Rhode Island South Shore Regional Sediment Management study. Additional information about the CMS nested grids for the RISRSM study will be provided in a technical report in the near future.

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> Lin, L., I. Watts, and Z. Demirbilek. 2010. *CMS-Wave model: Part 3. Grid Nesting and Application Example for Rhode Island South Shore Regional Sediment Management Study*. Coastal Inlets Research Program, ERDC/CHL CHETN-IV-76. Vicksburg, MS: U.S. Army Engineer Research and Development Center. An electronic copy of this CHETN is available from *http://chl.erdc.usace.army.mil/chetn*.

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